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DEVELOPING THE 'INDUSTRIAL COMMONS' FOR THE OFF-SITE CONSTRUCTION SECTOR

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Abstract

The paper explores the application of the Industrial Commons concept to Off-Site Construction (OSC), highlighting the significance of shared assets like research and development facilities, educational institutions, standardization bodies, open-source models & industrial operations for fostering growth in OSC sector. Emphasizing the need for collaboration, the study addresses the current state of the Canadian Industrial Commons for OSC, noting challenges such as high costs of individual design and fabrication software, leading to disconnected workflows and a lack of collaboration in areas like off-site quality control, post-fabrication task management, and on-site visualization. The proposed solution introduces curriculum based on open-source components, leveraging Linux-OS, Git Version Control, IFCShell, IFC.js, and BlenderBIM. This comprehensive approach aims to cover design, version control, fabrication aligned with the CSA-A277 standard, BCF-based collaboration, and 4-D visualization. The ultimate objective is to revitalize the Industrial Commons specific to OSC, providing small businesses with accessible templates to enhance efficiency and delivery in the industry. The paper presents a practical demonstration of how this open-source workflow can contribute to a rejuvenated Industrial Commons in the realm of Off-Site Construction.

Keywords: Off-Site Construction, Industrial Commons, Open-Source Workflows, Collaborative Innovation.

1 INTRODUCTION

The construction industry plays a critical role in the economic development of Canada, providing places for people to live and contributing significantly to employment generation and infrastructure development. However, for a number of reasons which I shall only allude to here, it is now in a bubble draining finances from other sectors of the economy and failing in its social contract to provide affordable housing. However, in recent years, the off-site construction sector has emerged as a promising avenue for enhancing efficiency, reducing costs, and mitigating environmental impacts. Off-site construction (OSC), also known as modular or prefabricated construction, involves the fabrication and assembly of building components in a controlled factory environment before transporting them to the construction site for final assembly.

In Canada, the OSC sector has garnered increasing attention due to its potential to address challenges such as skilled labor shortages, project delays and cost overruns. However, the full realization of its benefits hinges on the ability of industry stakeholders to foster collaborative innovation and knowledge sharing. At the heart of this endeavor lies the concept of "Industrial Commons", which encompasses shared resources, knowledge, and capabilities within an industry or geographic region.

In the construction sector today, the Commons has been gradually eroded. The problematic nature of this erosion of the Commons is marked by excessive and fragmented municipal regulation developed and implemented opaquely; expensive and excessive standards around building construction, ignoring of local building materials and proprietary software that doesn't facilitate process flows.

This paper attempts to solve this problem. Please see section 2.3 for additional discussion.

2 LITERATURE REVIEW

Industrial Commons [Pisano & Shih 2012] serve as catalysts for innovation, driving productivity gains, and fostering sustainable growth within industries. By facilitating collaboration among firms, research institutions, and government agencies, industrial commons create an ecosystem conducive to knowledge exchange, technology diffusion, and collective problem-solving. In the context of the off-site construction sector, re vitalizing industrial commons holds the key to unlocking the sector's full potential and addressing persistent challenges.

2.1 The DISCREDITED NOTION OF THE "TRAGEDY OF THE COMMONS"

The concept of the "Tragedy of the Commons," which has been historically used to illustrate the failure of shared resource management where individual users act against the common good, has been significantly reassessed in recent scholarship. Initially presented by William Forster Lloyd [Lloyd 1833] and popularized by Garrett Hardin [Hardin 1995], the theory suggested that individuals inevitably overuse and deplete common physical and knowledge resources, leading to skill fragmentation and scarcity.

However, the work of Elinor Ostrom [Ostrom 1990], a Nobel laureate in Economics, has effectively challenged this perspective. Ostrom's research demonstrated that communities could manage their resources sustainably without external interventions when appropriate collective action and governance structures are in place. Her findings showed that with mutual agreements and self-regulation, common resources and knowledge could be managed efficiently and sustainably.

Further discrediting the old notion, modern examples of open-source software and creative commons licensing illustrate how large groups can collaboratively manage resources and create value, challenging the inevitability of the tragedy scenario. These examples highlight the potential for collective responsibility and innovation, offering valuable lessons for the Off-Site Construction (OSC) sector.

In the context of OSC, revitalizing the Industrial Commons by embracing collaborative practices and shared resources can lead to enhanced innovation and efficiency. This approach counters the outdated tragedy narrative, proposing a model where shared infrastructure, knowledge, and tools are managed cooperatively to foster growth and sustainability in the construction industry.

2.2 General FACTORS AFFECTING INDUSTRIAL COMMONS

In exploring the development of the Industrial Commons within the Canadian Off-Site Construction (OSC) sector, several systemic barriers emerge. These obstacles not only limit the sector's growth but also its capacity to fully leverage the benefits of shared knowledge and resources.

Factor 1: Specialization of Labour in a Capitalist System: The capitalist emphasis on labor specialization necessitates individuals to focus on narrow sets of tasks, which, while beneficial for executing specific roles efficiently, often leads to competition rather than collaboration across different construction phases. This is discussed in depth in [Durkheim1893]. This segmented approach restricts the flow of knowledge and hinders the development of holistic solutions that could benefit the industry as a whole. The challenge is further compounded in the OSC sector, where the integration of various specialized tasks could significantly enhance both efficiency and product quality.

Factor 2: Specialization of Education, Processes, and Digital Systems: Education systems tailored to the capitalist structure tend to perpetuate economic divisions of labor, preparing individuals to fill predetermined roles within a hierarchical workforce rather than fostering a broader understanding of the construction process. This is discussed in depth in [Bowles and Gintis 1976]. This educational model reinforces the barriers to interdisciplinary knowledge and collaboration, essential for driving innovation in OSC. Similarly, the digital tools used in construction often operate in silos, with software platforms focusing on specialized tasks without adequate interoperability, thus fragmenting the workflow and limiting collaborative potential.

Factor 3: Large Volume Centralized Supply Chains: The OSC sector is also constrained by centralized, high-volume supply chains that often overlook local materials and manufacturing solutions. This centralization can lead to inefficiencies and increased environmental impacts due to the transportation of materials over long distances. Promoting more localized supply chains could enhance material utilization efficiency, reduce carbon footprints, and foster local economies, aligning with sustainable construction practices.

Factor 4: Specialized Codes & Regulation by Feudal Bureaucracies: Regulatory frameworks and building codes often lack transparency and flexibility, acting as barriers to innovation. The tendency of regulatory bodies to operate in a protective, gate-keeping manner can discourage the adoption of new technologies and methods in construction. [Graeber 2015] This is particularly problematic in OSC, where innovative, modular, and prefabricated solutions frequently encounter outdated or unsupportive regulatory environments.

Factor 5: Disincentives to Financial Sectors: Finally, the financial structures that dominate the Canadian economy tend to prioritize short-term gains over long-term sustainability and affordability. The wealthiest segments of society disproportionately influence investment decisions, often at the expense of the housing needs of the less affluent. (In Canada the wealthiest 20% of the population account for more than two-thirds (67.8%) of net worth, while the least wealthy 40% account for a mere 2.7%.) [Government of Canada 2023] In such a socioeconomic landscape, the financial markets are primarily concerned with extracting surplus and monetizing their investments, rather than addressing the housing needs of the bottom 40% of the population. This misalignment of financial incentives with societal needs impedes the development of a robust Industrial Commons that could support more equitable and sustainable construction practices. These factors are additionally discussed in [Christophers 2020]

By addressing these factors, stakeholders in the OSC sector can foster a more collaborative and innovative environment, ultimately leading to the revitalization of the Industrial Commons and enhanced sector performance.

2.3 Problem Statement:

Despite the promising potential of Off-Site Construction (OSC) to change the building industry by enhancing efficiency and reducing costs, its full realization is hampered by systemic barriers rooted in the specialization of education, processes, and digital systems. These barriers not only perpetuate siloed operations but also impede collaborative practices essential for the sector's growth.

The current educational systems in the construction industry predominantly prepare workers for narrowly defined roles, limiting their ability to understand the entire process of approval, fabrication and assembly and to build houses quickly. Simultaneously, digital systems within the industry are often disjointed, with proprietary software solutions creating significant interoperability challenges that disrupt workflow continuity and collaborative potential.

This research identifies and addresses the critical disconnects within these areas, aiming to propose a framework that leverages open-source solutions and integrated educational strategies. By doing so, the study seeks to foster a revitalized Industrial Commons that can support a more cohesive and innovative OSC sector that allows small business to enter the market. The expected outcome contributing directly to small businesses to meet the growing demand for affordable housing.

3 METHODOLOGY & LITERATURE REVIEW

This section of the paper outlines the approach taken to investigate the potential revitalization of the Industrial Commons in the Off-Site Construction (OSC) sector. It is divided into two main parts: a comprehensive literature review and a practical assessment of digital tools.

3.1 Literature Review:

The literature review undertaken for this study was extensive, encompassing a broad span of topics relevant to both the historical context and current state of Industrial Commons and software use in construction. The historical aspect of the review traces the evolution of economic systems and educational paradigms over the past 500 years, providing a deep understanding of how Industrial Commons have developed and their impact on industries. This historical perspective is crucial for identifying the underlying principles that can be applied to modern practices.

In contrast, the review of current software practices is focused on recent developments in digital tools within the construction industry. This part of the review examines the capabilities and limitations of existing proprietary software solutions like Revit, AutoCAD-3D, and others, as well as open-source alternatives that could potentially support the OSC sector more effectively. This dual approach allows for a comprehensive understanding of both the theoretical framework and practical tools available for fostering an Industrial Commons in OSC.

3.2 Practical Assessment:

The practical component of the methodology involves hands-on testing and comparison of digital tools. The author personally installed and tested several software platforms, both proprietary and open source, to evaluate their suitability for OSC processes. This direct engagement with the tools provides a grounded assessment of their functionality, user-friendliness, and interoperability — key factors that influence their utility in a collaborative OSC environment.

The assessment criteria were specifically designed to examine how well these tools meet the process-requirements of OSC, such as design flexibility, version control, and ease of integration into standardized workflows. Each tool was evaluated against a list of essential features needed to support effective collaboration and efficiency in OSC projects.

3.3 Integration of Findings:

The author reviewed literature in the areas “Industrial Commons” and “Software”. The review of the Industrial Commons was extensive and based the evolution of economic and education systems over the past 500 years; while the review of software is more current. As much as is possible, the software was installed and tested by the author.

4 FINDINGS

The findings of this study are presented in two parts: an analysis of the evolution of the Industrial Commons and an evaluation of the suitability of Architecture, Engineering, and Construction (AEC) software for supporting these commons in the Off-Site Construction (OSC) sector.

4.1 Industrial Commons:

The investigation into the historical evolution of the Industrial Commons reveals significant shifts that have shaped the modern landscape of industrial collaboration. Starting with the privatization of common lands in the 1500s, the research highlights how traditional communal knowledge systems were disrupted, leading to a profound transformation in labor and production methods. This historical context is vital for understanding the barriers that have emerged in modern times, particularly in the way industries share resources and knowledge.

The transition from a master-craftsman system to one dominated by merchant capitalism introduced a new economic dynamic where knowledge became fragmented and proprietary. This shift, as seen through events like the Germany peasant rebellion and the English uprisings, marked a critical juncture where the communal sharing of knowledge and resources began to wane, making way for a more individualistic and competitive economic environment.

By the late 18th and 19th centuries, the Industrial Revolution further accelerated this process. Factory-based production became the norm, and traditional artisanal practices, which were more adaptive to local needs and knowledge, became marginalized. This historical analysis provides a clear line of sight into the challenges faced today in fostering a vibrant Industrial Commons in the OSC sector, where knowledge sharing and collaboration are often secondary to economic competition.

4.2 AEC Software Suitability:

Turning to the practical assessment of current digital tools, the study evaluates several AEC software solutions, including both proprietary tools like Revit, AutoCAD-3D, and open-source platforms like BlenderBIM and Compas.dev. The evaluation focused on their capacity to support collaborative workflows, interoperability, and customization—key aspects that are crucial for revitalizing the Industrial Commons in OSC.

The findings indicate that while proprietary software offers robust functionality, it often falls short in interoperability and openness, which are essential for collaborative projects across different stakeholders. The proprietary nature of these tools leads to siloed data environments where sharing and integrating information across various platforms is cumbersome and inefficient.

In contrast, open-source software shows significant promise in addressing these limitations. Tools like BlenderBIM and Compas.dev, for example, offer extensive customization capabilities and foster a more collaborative environment by allowing users to modify and share the codebase. The use of open standards like IFC (Industry Foundation Classes) further enhances interoperability among different software, facilitating a more integrated and seamless workflow that is essential for the OSC sector.

4.3 Integration and Recommendations:

Integrating these findings, this paper proposes a pathway towards a more collaborative and efficient use of digital tools in OSC. By leveraging the strengths of open-source platforms and enhancing the interoperability of all tools, the OSC sector can better realize the benefits of a shared Industrial Commons. This approach not only aligns with the historical insights on communal resource management but also addresses the practical needs of today’s construction projects.

5 ASSESSMENT CRITERIA

To effectively evaluate the suitability of software for supporting the Industrial Commons in the Off-Site Construction (OSC) sector, a set of comprehensive assessment criteria was developed. These criteria are designed to address the unique needs of OSC, focusing on the functionalities that are crucial for enhancing collaboration, efficiency, and innovation in construction processes. The criteria cover various aspects of software functionality, which are essential for supporting the full lifecycle of construction projects, from initial design through to on-site assembly and project management.

5.1 Form Finding:

The ability to perform form finding is essential for designing complex geometries often used in modern construction. Software must support dynamic modeling and adaptation to diverse design requirements, enabling architects and engineers to explore innovative structural forms efficiently.

5.2 Structural Analysis:

Software should provide robust tools for structural analysis to ensure the viability and safety of designs. This includes the capability to simulate different load conditions and assess the structural integrity of various materials and configurations.

5.3 Site Planning:

Effective site planning tools are necessary for optimizing the layout and logistics of construction sites. This includes geospatial analysis, terrain adaptation, and the integration of site-specific constraints into the project planning process.

5.4 Building Design:

Comprehensive building design capabilities are crucial, encompassing everything from the architectural detailing to the integration of mechanical, electrical, and plumbing (MEP) systems. Software must facilitate the creation of detailed, accurate, and scalable models.

5.5 Modularization and Hierarchies:

Given the nature of OSC, software must support modularization and the creation of hierarchical structures. This allows for the pre-fabrication of wall panels and kitchen modules in a controlled environment, which are then assembled on site, enhancing speed and efficiency.

5.6 Costing:

Cost estimation tools are vital for budget management and financial planning throughout the construction process. Software should allow for real-time costing updates as design changes occur, helping project managers to keep budgets under control.

5.7 Version Controls:

Version control is fundamental in collaborative projects to track changes, manage iterations, and ensure all stakeholders are working from the most current plans. This is crucial in avoiding conflicts and redundancy in work.

5.8 Task Management:

Task management functionalities are required to schedule, assign, and track the progress of different tasks across multiple teams. This helps in maintaining project timelines and ensuring efficient use of resources.

5.9 Fabrication Instructions to CNC and Framing Stations:

The software should facilitate the seamless translation of digital models into fabrication instructions for computer numerical control (CNC) machinery and framing stations, crucial for prefabricating building components.

5.10 Logistics - Weight and Centre of Gravity:

Effective management of logistics, including calculations for weight and center of gravity, is essential for the safe and efficient transport and assembly of prefabricated components.

5.11 Logistics - Load Planning:

Load planning tools are necessary for optimizing the transportation of materials and components from the factory to the construction site, ensuring that loads are balanced and comply with transportation regulations.

5.12 Logistics - On-Site Assembly:

Software should support the planning and visualization of on-site assembly processes, helping teams understand assembly sequences and requirements beforehand, thus reducing on-site errors and delays.

5.13 On-Site Project Management:

Comprehensive project management tools are essential for overseeing the execution phase, tracking progress, and facilitating communication among all stakeholders involved in the project.

These criteria form the basis for evaluating the selected software tools, assessing their capabilities to meet the demands of the OSC sector and contribute effectively to the revitalization of the Industrial Commons.

6 ASSESSMENT RESULTS

The next sections detail the assessment of individual software solutions against these criteria.

6.1 Form Finding – Compas.dev and related Python libraries:

Compas.dev is a Python framework for computational research and collaboration in architecture, engineering, and digital fabrication. It includes modules for form finding, structural analysis, and geometric optimization, among others. [Compas.dev 2024]

6.2 Structural Analysis: Matplotlib, sfepy

Matplotlib is primarily a visualization library, commonly used for plotting graphs and charts, rather than performing structural analysis. However, it can be used to visualize results obtained from other structural analysis software.

Sfepy is a Python library for performing finite element analysis (FEA), allowing engineers to solve complex structural problems using numerical methods. [SfePy 2024]

6.3 Site Planning: QGIS:

QGIS is an open-source geographic information system (GIS) software that allows users to create, edit, visualize, and analyze geospatial data. It is widely used for site planning, land use analysis, and environmental modeling in civil engineering projects. [QGIS 2024]

6.4 Building Design: BlenderBIM with IfcOpenShell:

BlenderBIM [BlenderBIM 2024] is an open-source Building Information Modeling (BIM) software based on the Blender platform. It provides tools for architectural design, modeling, and documentation, allowing users to create detailed building designs and collaborate on construction projects. BlenderBIM utilizes IfcOpenShell [IfcOpenShell 2024] for handling Industry Foundation Classes (IFC) data, enabling interoperability with other BIM software and industry standards.

6.5 Modularization and Hierarchies: BlenderBIM with IfcOpenShell:

BlenderBIM, in conjunction with IfcOpenShell, supports modularization and hierarchical structuring of building components, enabling users to organize complex building designs into manageable parts and assemblies. This issues the IfcElementAssembly class [IfcElementAssembly 2024]

6.6 Costing:

BlenderBIM as it allows manipulation of the IFCCostSchedule object. [IfcCostSchedule 2024]

6.7 Version Control of Drawing: GIT:

Git is a widely used version control system that allows users to track changes in files and collaborate with others on software development projects. While primarily designed for computer programming code, it can also be used for version control of drawings and other project documents. [Git 2019]

6.8 Task Management – Design Domain: GIT:

Git can be used for task management in the design domain by utilizing its issue tracking and project management features, such as creating tasks, assigning them to team members, and tracking their progress.

6.9 Documentation and Reporting:

Git can be used to generate reports and documents.

6.10 Fabrication instructions to CNC and Framing Stations:

Unfortunately, the author is unable to find software that will allow a smooth transition from BlenderBIM to CNC machines and framing stations.

6.11 Logistics - Weight and Centre of Gravity:

Unfortunately, no software exists and a software will need to be developed.

6.12 Logistics - Load Planning:

Unfortunately, no software exits and some software will need to be developed.

6.13 Logistics - On-Site Assembly: BlenderBIM with IfcOpenShell:

BlenderBIM, with the assistance of IfcOpenShell, provides features for on-site assembly planning and coordination, allowing users to visualize construction sequences and simulate assembly processes within the BIM environment.

6.14 On-Site Project Management: BlenderBIM with IfcOpenShell:

BlenderBIM, leveraging IfcOpenShell, includes project management tools for coordinating on-site activities, tracking progress, and communicating with stakeholders during construction projects. It offers a comprehensive solution for managing the entire construction process within the BIM environment.

7 DISCUSSION

The assessment of software tools for the off-site construction (OSC) sector reveals both promising capabilities and notable limitations in existing solutions. By considering the implications of these findings, we can better understand the challenges and opportunities in leveraging software to support the Industrial Commons in OSC.

The lack of integration and interoperability among proprietary software packages poses a significant barrier to reducing costs and increasing affordability in this sector. Siloed workflows hinder knowledge sharing and hinder the development of holistic solutions. Additionally, the opaque nature of proprietary software limits customization and inhibits users' ability to optimize workflows for their specific needs.

Conversely, open-source solutions such as Compas.dev, QGIS, and BlenderBIM offer greater flexibility, transparency, and potential for collaboration. These platforms provide a foundation for interdisciplinary cooperation and knowledge exchange, empowering tradespeople to build homes faster and cheaper.

However, gaps remain in the current software landscape, particularly concerning fabrication & logistics. Addressing these gaps will require concerted efforts from industry stakeholders, software developers, and policymakers to prioritize the development of specialized tools and standards that meet the unique needs of the OSC sector.

Strategic planning in education and training are also crucial for fostering a skilled workforce capable of harnessing the full potential of available software tools. Curricula should be updated to include training on open-source platforms and interdisciplinary collaboration, ensuring that future professionals are equipped with the necessary knowledge and skills to thrive in the OSC industry.

8 PAPER CONTRIBUTIONS - POLICY & CURRICULUM RECOMMENDATIONS

Based on the discussion and findings from the previous sections, several policy recommendations can be proposed to enhance the effectiveness of the Industrial Commons in the Off-Site Construction (OSC) sector. These recommendations are designed to address the identified gaps and leverage opportunities for fostering collaboration and innovation. The following curriculum is proposed:

8.1 Form Finding & Structural Analysis Stream:

- Course 1: Introduction to Computational Design and Structural Analysis using Compas.dev. Train students with the skills to utilize computational tools for complex architectural and engineering challenges. The primary objective being to reduce material consumption and to speed up certification processes.

- Course 2: Structural Engineering Principles and Analysis Techniques using Python. Provide foundational knowledge in structural engineering, using Python to implement and solve real-world problems.

8.2 Building Design Stream:

- Course 1: Architectural Design Fundamentals. Offer a comprehensive overview of architectural design principles.

- Course 2: Building Information Modeling (BIM) with IFC, OpenIFCShell & BlenderBIM. Train students in the use of BIM technologies that support open formats, enhancing interoperability and collaboration across different professional disciplines. The primary objective being a clear understanding of IFC classes, hierarchies and operations.

8.3 Fabrication Stream:

- Course 1: Introduction to Panelized and Modular Structures. Focus on the design, fabrication, and assembly of panelized and modular components, critical for accelerating construction timelines and reducing waste.

- Course 2: Overview of CSA-A277 Compliance. Train students on the standards and regulations governing the construction of prefabricated buildings. This will ensure buildings are approved quickly, manufactured quickly and certified on-site rapidly.

8.4 Logistics Stream:

- Course 1: Introduction to Logistics and Supply Chain Management in Construction. Explore the fundamentals of logistics and supply chain management tailored to panel and modular.

- Course 2: 4-D Visualization using BlenderBIM. Develop skills in advanced visualization techniques that facilitate better planning and execution of construction projects.

- Course 3: Task Management & Project Management using BlenderBIM and Git. Provide training on project management tools that enhance collaboration, efficiency, and accountability in construction projects.

9 Conclusion

In conclusion, revitalizing the Industrial Commons in the Off-Site Construction (OSC) sector is crucial for reducing costs, increasing affordability and building communities. By addressing the identified challenges and implementing targeted strategies, this paper demonstrates that it is possible to enable small businesses and tradespeople to deliver OSC solutions.

The findings from the evaluation of current software tools reveal significant opportunities for enhancing collaborative practices through the adoption of open-source solutions and the development of new technologies tailored to the specific needs of OSC. Tools like BlenderBIM and Compas.dev, which support open standards and interoperability, are shown to be particularly valuable. However, gaps in areas such as fabrication and logistics highlight the need for continued innovation and development in specialized software.

The proposed educational curriculum streams aim to equip future professionals with the skills necessary to navigate and innovate within the OSC sector. By focusing on computational design, structural analysis, building design, logistics, and project management, these curricula will help build a workforce capable of leveraging advanced technologies and collaborative methodologies.

Policy recommendations focus on supporting the adoption of open standards, promoting open-source software initiatives, fostering industry-academia partnerships, and encouraging the use of modular and prefabricated construction methods. These strategies are designed to overcome existing barriers to innovation and collaboration, facilitating a more integrated and responsive Industrial Commons.

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